NBSIR 78-1484 (HEW)

Arousal from Sleep by Emergency Alarms: Implications from the Scientific Literature

V. J. Pezoldt
Harold P. Van Cott

Consumer Sciences Division
Center for Consumer Product Technology
National Engineering Laboratory
National Bureau of Standards
Washington, D.C. 20234

June 1978

Prepared for the Center for Fire Research, in support of:
HEW-NBS Fire/Life Safety Program

Sponsored by:

U.S. Public Health Service
Department of Health, Education and Welfare
Washington, D.C. 20203

NBSIR 78-1484 (HEW)

AROUSAL FROM SLEEP BY EMERGENCY ALARMS: IMPLICATIONS FROM THE SCIENTIFIC LITERATURE

V. J. Pezoldt
Harold P. Van Cott

Consumer Sciences Division
Center for Consumer Product Technology
National Engineering Laboratory
National Bureau of Standards
Washington, D.C. 20234

June 1978

Prepared for the Center for Fire Research, in support of:
HEW-NBS Fire/Life Safety Program

Sponsored by:
U.S. Public Health Service
Department of Health, Education and Welfare
Washington, D.C. 20203

U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

Dr. Sidney Harman, *Under Secretary*

Jordan J. Baruch, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

PREFACE

This report is a product of a joint effort of the Department of Health, Education and Welfare and the National Bureau of Standards Center for Fire Research. The program is a five-year activity initiated in 1975. It consists of projects in the areas of: decision analysis, fire and smoke detection, smoke movement and control, automatic extinguishment, and behavior of institutional populations in fire situations.

This report contains a review of the sleep research and other literature which pertains to the effectiveness of external signals, especially the intensity and other characteristics of sound, in awakening people from sleep. This information should prove useful in evaluating fire protection systems that rely on alarms to awaken building occupants and assist in the design of the sound characteristics of such alarms. The requirements for needed future research are highlighted.

Table of Contents

Acknowledgements

The authors wish to acknowledge the contributions of Dr. Wilse B. Webb and his staff at the University of Florida in providing us with use of their sleep research library from which many of the references cited in this report originated.

Abstract

A review of the sleep research and other scientific literature pertaining to the arousal of sleeping individuals by external stimuli is reported. This effort was undertaken to provide information about the characteristics of emergency alarms which will reliably awaken a sleeping population, especially nursing home residents, in the event of fire. The literature reviewed does not provide an adequate basis for specifying signal characteristics which will offer a high assurance of producing arousal. Among the factors that influence the intensity of a signal which will produce arousal are the age and physical/mental condition of the sleeper, drug use, sleep stage, time of night, and meaningfulness or personal significance of the signal. Data relevant to these variables arediscussed as is the problem of performance following abrupt arousal. Recommendations regarding stimulus characteristics, measures of arousal and the experimental environment for future studies of arousal by emergency alarms are presented.

AROUSAL FROM SLEEP BY EMERGENCY ALARMS: IMPLICATIONS FROM THE SCIENTIFIC LITERATURE

The National Fire Protection Association estimates that 6,200 people died in residential fires in the United States in 1976 (Derry, 1977). Many of these deaths are believed to involve sleeping persons. One approach to the reduction of fire fatalities that occur while persons are sleeping is to identify and incorporate into the design of emergency alarms, signal characteristics that will reliably arouse a large percentage of sleepers to an awakening state.

Of particular interest in this report are the determinants of arousal from sleep of individuals representative of the population residing in nursing homes and similar limited care institutional facilities. This population is composed primarily of elderly individuals who may during both day and night be under the influence of one or more forms of medication, including sedatives, and who may be suffering from a variety of physical and emotional problems which may affect depth of sleep, speed of arousal from sleep, and the ability to respond adaptively to an emergency alarm by choosing and implementing an appropriate series of evasive and protective responses.

This report examines the scientific literature which bears upon those signal characteristics which reliably awaken the sleeping individual and the behaviors that occur in the post-arousal state. Particular emphasis was placed on the identification and analysis of research on the independent variables of signal type and signal properties, age, sex, and medical condition that affect arousal, particularly as evidenced in the sleep literature.

This report does not address the important question of the desirability or appropriateness of waking people in the event of fire. Arguments can be advanced which suggest that under certain institutional and emergency conditions it may be preferable not to arouse individuals. No position regarding this issue is taken here. Rather, the question addressed is concerned with how to awaken individuals in emergency situations.

The Phenomena of Sleep

Although the emphasis of this report is on arousal by means of external signals, arousal is closely related to sleep, its depth and its duration. Therefore, it is important to understand the phenomena of sleep before considering the process of arousal.

Sleep has been the subject of great fascination probably for as long as people have recognized that they sleep. The scientific study of sleep, however, has a relatively short, but prolific history. Webb (1977) dates the experimental analysis of sleep from Kohlschutter's attempt to measure arousal thresholds during sleep in 1862. Modern sleep research provides us with a good description, if not a full explanation, of much of the sleep process. Much of the progress in sleep research is attributable to the discovery of consistent, quantifiable patterns of brain activity during sleep as recorded on the electroencephalograph (EEG). From the pioneering work of Loomis, Harvey and Hobart (1937), Davis, et al. (1937) and, more recently, Dement and Kleitman (1957) in the identification and measurement of human brain potentials during sleep, a generally accepted means of describing sleep in terms of EEG patterns has evolved. Although various investigators employ somewhat different measurement methods and criteria, there is a high degree of uniformity among the procedures used. Most researchers use criteria similar to those established by Rechtschaffen and Kales (1968) who refined the scoring system of Dement and Kleitman (1957). EEG records, obtained by amplifying the electrical potentials from scalp electrodes, are analyzed in short (typically 30-60s) epochs which are assigned to the various sleep stages on the basis of the amplitude and frequency of the EEG pattern and associated electrooculograph (EOG) records.

The scoring criteria for sleep classification used by Webb (1969) is typical. Each 60s epoch is scored independently and assigned to one of six classification categories using the following crtieria:

Stage 0: At least 30s of 8-12 Hz (alpha waves) of occipital activity with a minimum of 20μV. This is a resting, waking state with eyes closed which precedes sleep.

Stage 1: Less than 30s of 8-12 Hz of 20μV occipital activity and no more than one well defined sleep spindle or K-complex. "Sleep spindles" are very brief bursts (0.5 - 2s) of 13-16 Hz waves. "K-complexes" are sharp rises and falls and recovery of the EEG.

Stage 2: An epoch containing at least two well defined sleep spindles or K-complexes, or one of each, and no more than 12s of 0.5 - 3 Hz (delta waves).

Stage 3: An epoch containing at least 13s of 0.5 - 3 Hz, 20μV or higher activity, but less than 30s of this activity.

Stage 4: An epoch containing at least 30s of 0.5 - 3 Hz, 20μV or higher slow wave activity.

Stage 1-REM: A stage 1 EEG plus evidence of conjugate rapid eye movements (REM) as evidenced by EOG recordings of the movement of the eyeball.

Minor variations in this classification system are common. Often stages 3 and 4 are not differentiated from each other. They may be reported as a single stage referred to as stage 3-4, slow-wave or delta sleep. In other cases, the various stages are summarized dichotomously, with descending stage 1 and stages 2, 3, and 4 described as non-REM (NREM) sleep and ascending stage 1-REM described as REM sleep. The discovery of rapid eye movements (REM) during sleep (Aserinsky and Kleitman, 1953) has provided the source for much of the modern sleep research since dreaming is considered to occur primarily, though not exclusively, during REM sleep.

The functional significance of the various sleep stages has not been clearly established and is the subject of considerable controversy. There is, however, general agreement about the relatively stable, cyclic nature of the sleep stages within individuals. Changes from stage to stage are generally sequential from stage 1 through stage 4 and from stage 4 to stage 1. Abrupt changes from stage 4 to stage 2 or 1, however, do occur. REM sleep typically emerges from and returns to stage 2 (Webb, 1969). REMs typically first appear approximately 90 minutes after sleep onset and reappear every 90-100 minutes thereafter throughout the sleep period (Johnson, 1973). The cyclic occurrence of the sleep stages is illustrated in Figure 1, adapted from Webb (1971).

As evidenced in Figure 1 and by additional data from Webb (1969), the time spent in the various sleep stages is not distributed equally across the total night of sleep. Rather, stage 4 occurs predominantly in the first third of the night, while REM sleep is increasingly predominant in the last third. Davies (1976) reports a similar trend based on his review of several studies. That is, delta (stages 3 and 4) occurs predominantly in the first half of the sleep period with successive delta periods becoming progressively shorter, whereas REM appears predominantly, though not exclussively, in the second half of the night. Successive REM periods become progressively longer.

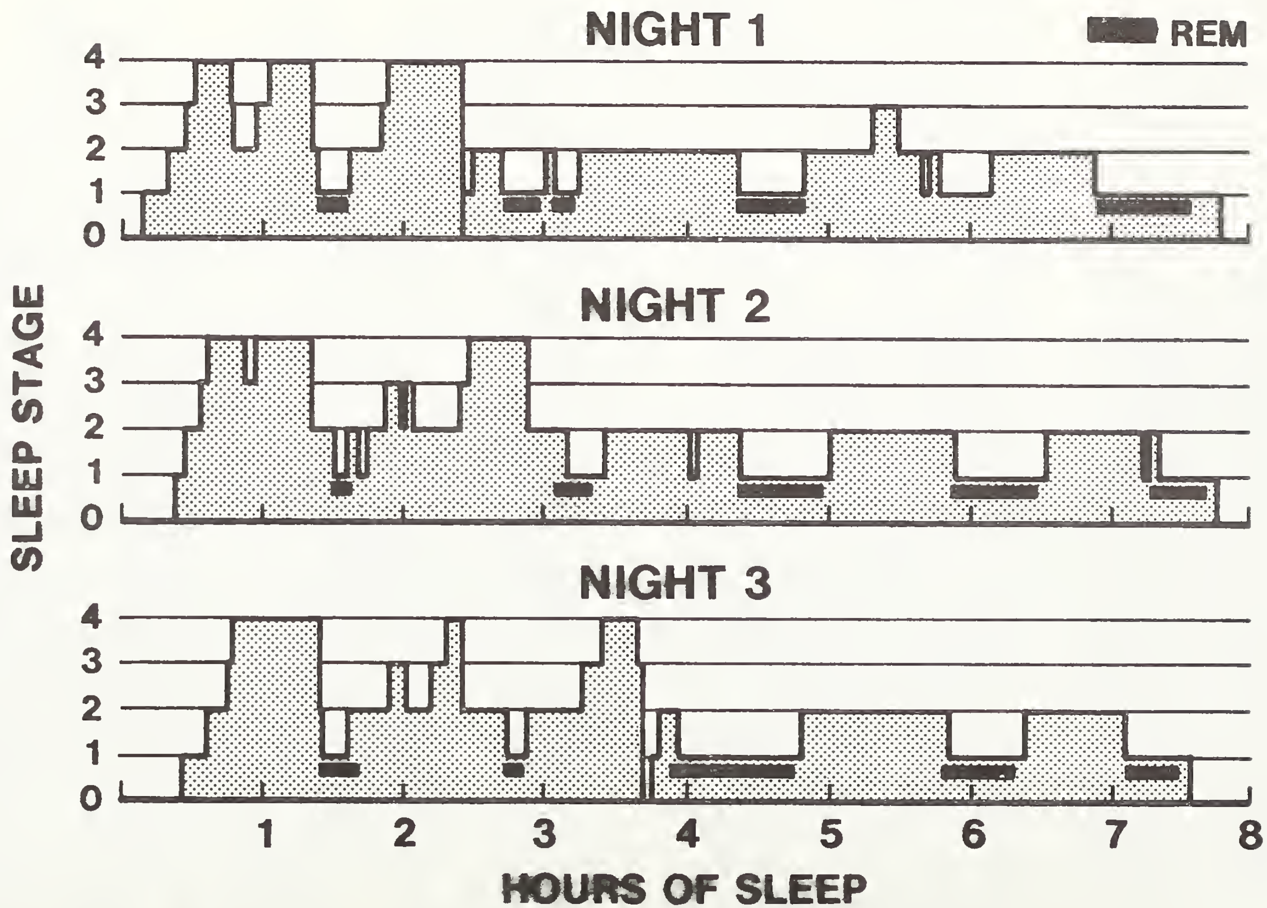

Figure 1. Cyclic progression of sleep stages for one subject across three uninterrupted nights. (Source: Webb, 1971)

Some normative data revealing consistencies in the proportion of total sleep in each stage as a function of age is available from Webb (1969) and Webb and Agnew (1969). Table 1 provides a comparison of the percent of sleep in each stage for six age groups. Webb concludes, from the data summarized in Table 1, that each individual appears to be programmed for certain overall amounts of the various stages and, although there are consistencies among people in the same age group, these tendencies vary from individual to individual. Again, Davies (1976) reports very similar data, i.e., for young adults approximately 50 percent of total sleep time is in stage 2, 20 percent in stages 3 and 4, 25 percent in REM sleep and 5 percent in stages 0 and 1.

Several conclusions about the sleep of the elderly which have important implications for the design of effective emergency alarms can be drawn from the sleep literature. As shown in Table 1, the distribution of sleep in the EEG stages varies as a function of age. As will be seen later, the different EEG defined stages demonstrate different responsivity to a given signal.

Several researchers have demonstrated a marked decrease in stage 4 with increased age. A detailed account of a series of studies conducted at the University of Florida (Williams, Karacan and Hursch, 1974) indicates that after the age of 30, consistently fewer men than women exhibit stage 4 and, in the oldest group studied, stage 4 was completely absent in men and present in only five out of ten women. Typical of the Florida results are those reported by Agnew, Webb and Williams (1967) who found that 16 healthy 50-60 year old males exhibited stage 4 an average of only 2.7 percent of total sleep time over three nights of testing. For individual subjects, stage 4 ranged from 0 - 10.3 percent of total sleep time. Kales, et al. (1967), in a study of 10 drug-free, normal 64-87 year old subjects, report an average of 1.4 percent of total sleep time in stage 4. Data from Brezinova (1975) shows older subjects experienced as many episodes of delta and REM sleep as did younger subjects, but episodes of these stages were shorter in older subjects, thereby accumulating less total time in these states. Although all of these studies indicate decreased stage 4 as a function of increased age it is difficult to specify an absolute value for stage 4 in the elderly. Individual differences and, to a lesser extent, differences in scoring procedures and laboratory artifacts probably account for discrepancies between the values obtained in different studies. Feinberg, Koresko and Heller (1967), for example, report a mean of 7.3 percent (range 0 - 20.4 percent) of total sleep time exhibited stage 4 for 15 normal 65-

TABLE 1

Percent of Total Sleep in Each Sleep Stage*

Age Group	Sleep Stage 0	1	REM	2	3	4	Number of Subjects
21-31 mos.	2	8	29	43	--	18	16
8-11	2	6	24	44	6	18	18
16-19	(0-4)**	(2-11)	(18-30)	(29-52)	(2-9)	(12-24)	
16-19	1 (0-4)	5 (1-9)	23 (18-32)	47 (27-56)	6 (3-9)	18 (10-25)	32
20-29 Males	1 (0-2)	5 (0-16)	24 (17-32)	50 (39-59)	7 (3-15)	13 (3-22)	28
20-29 Females	1 (0-3)	6 (1-11)	22 (16-29)	48 (34-60)	7 (2-15)	16 (10-23)	16
30-39	2 (0-8)	8 (3-15)	22 (16-24)	53 (43-63)	5 (3-9)	10 (3-16)	12
50-59	4 (0-10)	11 (4-22)	23 (13-34)	51 (34-67)	8 (0-13)	3 (0-10)	16
60-69	9	12	20	51	5	3	16

* Source: Webb (1969) and Webb & Agnew (1969).

** Range across three nights mean for each subject.

96 year old subjects (mean = 77 years). Studies relating amount of stage 3 sleep as a function of age are less consistent. Some studies (e.g., Agnew, Webb and Williams, 1967) demonstrate a decrease in stage 3 with increased age and others (e.g., Feinberg, Koresko and Heller, 1967; Kales, et al., 1967) report an increase in stage 3 compared to younger subjects. The importance of stages 3 and 4 will be seen in the review of arousal threshold data which suggest that a greater signal intensity may be necessary to arouse individuals from stage 3 and 4 sleep than from stage 2 and REM.

Studies of the sleep of the elderly also indicate an increased latency to sleep onset (Agnew and Webb, 1971; Feinberg, Koresko and Heller, 1967) and an increase in spontaneous awakenings with increased age. Webb and Swinburne (1971) report a mean of 4.6 and 5.6 night arousals for males and females respectively, 66-96 years old. Williams, Karacan and Hursch (1974) suggest that "sleep efficiency," as defined by the total sleep time/total time in bed is gradually reduced with age from age 30 for men and 50 for women. From the mid 50's on, the reduction in sleep efficiency becomes more marked for both sexes. Tune (1969, 1969a) reports similar data. However, contrary to Williams, et al., Tune found that women are more prone to report sleep disruptions than men, particularly after the age of 50. Feinberg, Koresko and Heller (1967) report a mean of 5.4 spontaneous awakenings per night among their 65-96 year old subjects compared to only 3.1 such awakenings for 19-36 year old subjects. Feinberg, et al., further suggest that their elderly subjects awakened more rapidly from all stages of sleep than did younger subjects, noting that "while grogginess seemed to persist for rather prolonged periods after EEG arousal in children and young adults, elderly normal subjects appeared fully alert within minutes of EEG arousal."

In addition to the characteristic changes in sleep patterns that accompany normal aging, several other factors which affect sleep patterns should be noted as they may be relevant to populations residing in nursing homes or similar institutions. Regardless of the effects of age, Monroe (1967) found several differences between self-reported good and poor sleepers. "Good sleepers" demonstrate more total time asleep, less time in stage 2 and more time in REM than "poor sleepers." "Poor sleepers," on the other hand, took longer to reach delta sleep and longer to reach the first REM period of the night. The proportion of time spent in delta sleep, however, was about the same for good and poor sleepers.

Pathological aging, as evidenced in patients diagnosed as suffering chronic brain syndrome, tends to accentuate the changes seen in normal aging (Feinberg, Koresko and Heller, 1967). Similar results are apparent with clinically depressed patients who demonstrate more stage 0 (awake), less stage 4, and slightly longer latencies to sleep onset than non-depressed, matched subjects (Gresham, Agnew and Williams, 1965). Depressed subjects also show greater sensitivity to external sources of noise than do normal subjects (Zung, Wilson and Dodson, 1964).

The finding that a greater proportion of light sleep occurs in the elderly than the young has implications for arousing a nursing home population. It suggests that the elderly may be easier to arouse at almost any time during sleep than the young, unless there is some other extenuating factor, such as medication or hearing impairment. The higher frequency of spontaneous awakenings of the elderly compared with the young also suggests that other things being equal, the characteristics of alarms to be used in nursing homes may not need to be the same as for a younger population of, say, college dormitory students.

Arousal Thresholds and Depth of Sleep

An area of sleep research which provides potentially useful data regarding signal characteristics which will reliably awaken sleeping individuals in emergency situations is that which focuses on the problem of depth of sleep. Davies (1976) notes that "it is generally assumed that sleep stages vary in depth, the depth of sleep becoming progressively greater from stage 1 to stage 4." There has been, however, considerable controversy regarding depth of sleep. Measures of auditory arousal or awakening thresholds (AATs) have been employed by many investigators to address the issue of depth of sleep. It is from such threshold studies that some gross approximations of appropriate signal levels for emergency alarms can be obtained.

In an exhaustive review of the depth of sleep literature, Bonnet (1975) introduces the topic of threshold measurement by noting that "behavioral responsivity as a function of signal intensity is an intuitively obvious way to approach sleep and one that seems fairly simple. Unfortunately, it is not simple." Neither is it a simple matter to use threshold measures directly to suggest signal intensities (or other characteristics) necessary for emergency alarms. Much of the difficulty in applying these data arises from the fact that they were not obtained for the purpose of specifying alarm criteria. Specific problems associated with these data include (1) the criteria of arousal or awakening used; (2) the lack of adequate specification

of the signals employed; (3) the existence of experimental artifacts which confound direct application to fire alarms; and (4) the very wide variability reported among similar individuals (thus making generalizations to entire populations difficult). Since most threshold studies have been performed with young adults, generalization to the elderly, nursing home resident becomes even more tenuous. Nevertheless, AAT data are some of the best data currently available.

As Bonnet (1975) notes, threshold experiments present a large number of possible choices regarding stimulus selection (e.g., frequency, rise-time, impulse characteristics), method of presentation, stimulus duration and number of stimulus presentations, etc. There is also a wide choice of response measures, including EEG stage changes, physiological changes, EEG defined arousal (presence of alpha rhythm) and behavioral indications of awakening, e.g., button pressing or vocalizations.

Arousal Thresholds as a Function of Physical Signal Characteristics

Using a 500 Hz tone, increased in 5 dB steps with a 10s interstimulus interval (ISI) until the subject responded, Rechtschaffen and Lentzner (1960, reported in Bonnet, 1975) provide data to support the notion that sleep stage is related to sleep depth. A greater intensity was required to obtain a response from stage 4 than from stage 3; and from stage 3 than from stage 2, which was in turn greater than the intensity required for a response from stage 1. Watson and Rechtschaffen (1969), using a similar ascending method of limits with a 1000 Hz tone, report a maximum AAT of about 60 dB for stage 2 and REM. In both of these studies, sustained alpha (8 - 12 Hz) activity was the response. Although alpha activity is typically accompanied by behavioral awakening, it is not synonymous with behaviorally defined awakening. Langford, Meddis and Pearson (1974) reported considerably lower arousal latencies from stage 2 and REM for the onset of alpha rhythm than for pressing a microswitch taped to the subject's finger.

Rechtschaffen, Hauri and Zeitlein (1966) used a variant of the method of constant stimili rather than the ascending method of limits in a threshold study because of the possibility that stimuli which gradually increased in intensity may be incorporated into dreams. Over all stages of sleep the median AAT was about 65 dB above background level for a 2000 Hz tone of 5s duration. The response required was a vocalization of the number of "blips" presented at an intensity 5 dB below the signal tone a few seconds after the signal. Individual differences in

this study resulted in AATs ranging from 15 - 100 dB above background. Therefore, the median AAT should not be used as any absolute measure of awakening threshold. While Rechtschaffen, Hauri, and Zeitlein found no evidence of incorporation of the stimulus tone in REM sleep dreaming, Bradly and Meddis (1974) did, based on subject reports. Using a white noise stimulus of 5s duration increased in 4 dB steps with a 5s ISI, they found a 10 dB difference in AAT as a function of dream incorporation. The mean "unincorporated arousal" AAT was 59.9 dBA, while the mean for those arousals in which the signal was incorporated in a dream was 69.9 dBA. Again, the range of AATs was fairly large: 48 - 79 dBA.

In a study using a bell (otherwise unspecified) as the arousal stimulus and a behavioral response consisting of lifting a telephone receiver, Shapiro, Goodenough and Gryler (1963) report a mean AAT of 55 dB. This study employed an ascending series of signals of 10s duration with an ISI of 5s between 6 dB steps.

Keefe, Johnson and Hunter (1971) using a 1000 Hz tone of 5s duration presented in 5 dB steps with 55s between signals, report AATs for REM, slow wave sleep (stages 3 and 4), stage 2 day sleep and stage 2 night sleep. Mean AATs, respectively, were 74, 75, 61, and 76 dB. Unfortunately, the difference between day and night stage 2 arousals and the similarity among the AATs for the night sleep are difficult to evaluate because a between subjects rather than a repeated measures design was employed. The relatively large ISI (55s) used in this study reduces the likelihood of any additive effects of the increasing stimuli intensity. This may account for the somewhat higher mean AATs reported in this study than those previously reported. If this is indeed the case, it provides an important consideration in attempting to determine the "true" AAT for an alarm signal, namely, AATs derived from studies with short ISIs probably overestimate the responsivity of subjects to a tone of a given intensity.

Differences in AAT between "light" and "deep" sleepers were investigated by Zimmerman (1970). Using an ascending series (800 Hz tone, 1s duration, 5 dB steps, 8s ISI) with subjects responding "I am awake," Zimmerman reports a median AAT of 65 dBA over all sleep stages and all subjects. However, when the subjects were divided into "light" and "deep" sleepers and the data presented separately for the various sleep stages, a different picture emerges. Table 2 is a summary of Zimmerman's data. Several features of these data are worthy of note. First, the AAT from stage 2 sleep decreases, for both light and deep

TABLE 2

Auditory Awakening Thresholds (in dB) for a Light Sleep Group (LSG) and a Deep Sleep Group (DSG) on Each of Seven Awakenings*

Awaking	Sleep Stage	Means (dB)	
		LSG	DSG
#1	4	78.4	85.0
#2	2	60.3	75.9
#3	REM	56.6	70.9
#4	3	57.8	74.7
#5	2	55.7	70.3
#6	REM	55.0	72.3
#7	2	51.1	66.2

* Source: Zimmerman, 1970.

sleepers, as arousals are instigated later in the night. That is, the AAT for arousal #2 is higher than #5 is higher than #7. Responsivity to auditory stimulation, therefore, appears to increase as a function of time of night. This result may be interpreted as being contrary to results reported by Williams, et al. (1964) that show a behavioral response (button pressing) decreases for stage 2 as a function of time of night, suggesting that responsivity decreases as the night passes. One should also note the considerably higher AAT for stage 4 than for the other sleep stages.

Agnew, Shaw and Webb (unpublished manuscript, personal communication, Webb, 1977) further demonstrate the resistance of stage 4 to arousal by auditory stimuli. Of 36 arousal attempts during stage 4 (ascending series, 1000 Hz tone, 5 dB steps) verbally indicated arousals were obtained only seven times at less than 100 dB (Mean = 70 dB); five arousals were obtained only after a 100 dB signal was presented for 60s; and in 24 cases 70s of the 100 dB signal failed to produce arousal.

Arousal as a Function of Signal Meaningfulness and Sleeper Motivation

Thus far we have been concerned only with the intensity of relatively meaningless stimuli used to arouse subjects from sleep. Several studies point to the importance of the meaningfulness or motivating qualities of the signal.

Zung and Wilson (1961) found no significant differences in EEG stage changes as a function of familiarity or unfamiliarity with a variety of auditory stimuli including door chimes, trains, cars, telephones, Chinese gongs, artillery fire, bagpipes and monkey howls. However, subjects who were paid (i.e., motivated) on the basis of their ability to awaken to specific sounds (a telephone or bagpipes) responded more frequently to "motivating" stimuli than to "non-motivating" stimuli in all stages of sleep except stage 4. Zung and Wilson conclude that familiarity/unfamiliarity per se is not important, rather the motivating quality of a sound is the feature that evokes responses (in this case awakening) to some sounds and not to others.

Using essentially the same methodology, Wilson and Zung (1966) tested for sex differences in responses to meaningful (motivating) and neutral (non-motivating) sounds. In terms of the percent of sleep stage-change responses to neutral stimuli, females demonstrated a higher response rate than males.

Response rates to motivating stimuli did not differ as a function of sex; both males and females demonstrated a higher response rate to motivating than to neutral stimuli.

Williams, Morlock and Morlock (1963) informed subjects that either a 700 or 1300 Hz tone presented at low intensity (40 dB) was critical and the other was not. The subject was to respond to the critical signal by pressing a microswitch and disregard the non-critical signal. Under conditions of simple instruction, the proportion of signals to which responses were made were very low in stage 2, delta and REM (approximately .28, .08, and .05 respectively). On nights in which negative reinforcement (flashing lights, intense fire alarm, shock to the leg) resulted if there was no response to the critical signal, response rates were increased in all stages of sleep (stage 2 ≈ .48, delta ≈ .12, and REM ≈ .68).

Oswald, Taylor, and Triesman (1960) report a study in which subjects were instructed to awaken and clench their left fist whenever a name was spoken. They found that subjects reponded more often to their own name than to a designated signal name, and more often to the signal name than any other name. Oswald et al., also found that a subject's own name was more likely to produce a K-complex in the EEG record when played in the normal forward direction than when the same stimuli was played backward. Bonnet (1975) compared the results of Oswald et al. with those of Howarth and Ellis (1961) who employed a methodology much like Oswald et al., except that the subjects in the latter study were awake. Bonnet concludes that "discriminative capabilities in terms of the signal motivating properties associated with one's own name appear at least as great during sleep as during waking."

Langford, Meddis and Pearson (1974) instructed subjects to respond by pressing a microswitch whenever they heard a sound played over a loudspeaker while they slept. The subject's name was played both forward and backward at 50 dBA (10 dBA above background) during stage 2 and REM. Smaller response latencies (i.e., faster reaction times) were found to names played forward than names played backward for both sleep stages tested both for the button press response and for the onset of alpha rhythm. Reaction time, for both measures, was faster in REM than in stage 2. No interaction was found between sleep stage and stimulus type.

LeVere, Davis, Mills and Berger (1976) provide data which they interpret as reaffirming the contention that the cognitive value of a stimulus contributes to the sleep disruption

produced by an auditory stimulus. They suggest that those stimuli which have a greater potential for intrusion into sleep are those which have a consistent history of significance for the individual. Those stimuli which do not have significance to the individual are reacted to, if at all, solely on the basis of their physical characteristics.

Arousal as a Function of Noise

The impact of environmental noise on both our waking and sleeping behavior is an issue of increasing concern. Lukas (1975, 1975a) provides an extensive review of the effects of environmental noise on sleep and proposes a criterion for assessing the effect. From a review of approximately 90 studies which deal primarily with aircraft flyover noise and sonic booms, Lukas selected about 20 studies which permitted an adequate analysis of noise level and arousal criteria to identify the functional relationship between sound level and the predicted frequency of awakening or no sleep disturbance. Lukas suggests that, on the basis of available data, the frequency of no sleep disruption can be predicted more accurately than the frequency of EEG defined arousal or behavioral awakening. Figures 2 and 3 show these relationships.

The measure of noise level used by Lukas is EPNdB. The EPNdB concept takes into account the spectral characteristics and duration of environmental noise which are not accounted for in the more usual measures of dB or dBA. This measure was developed for assessing the noise nuisance from aircraft (see Kryter, 1970) and has meaning primarily in conjunction with such noises (Broch, 1969).

In an unpublished manuscript, Lukas provides a figure which shows the relationship between the percent of subjects behaviorally awakened and noise level in dBA units. The right-hand curve of Figure 4 is based on data from six studies primarily involving aircraft noise. Based on this curve, one would predict that approximately 80 percent of experimental subjects would be awakened by a noise of about 80 dBA. The left-hand curve of Figure 4 is based on data from Steinicke (reported in Lukas, 1975a). Steinicke's technique involved increasing noise level without a period of silence between levels. Thus, as the intensity increased, the signal duration also increased. This likely accounts for the discrepancy between Steinicke's results and those based on other investigations.

Data contained in the figures presented here are based on studies of "college and middle age" men and women. Each function would probably be displaced to the left for older subjects.

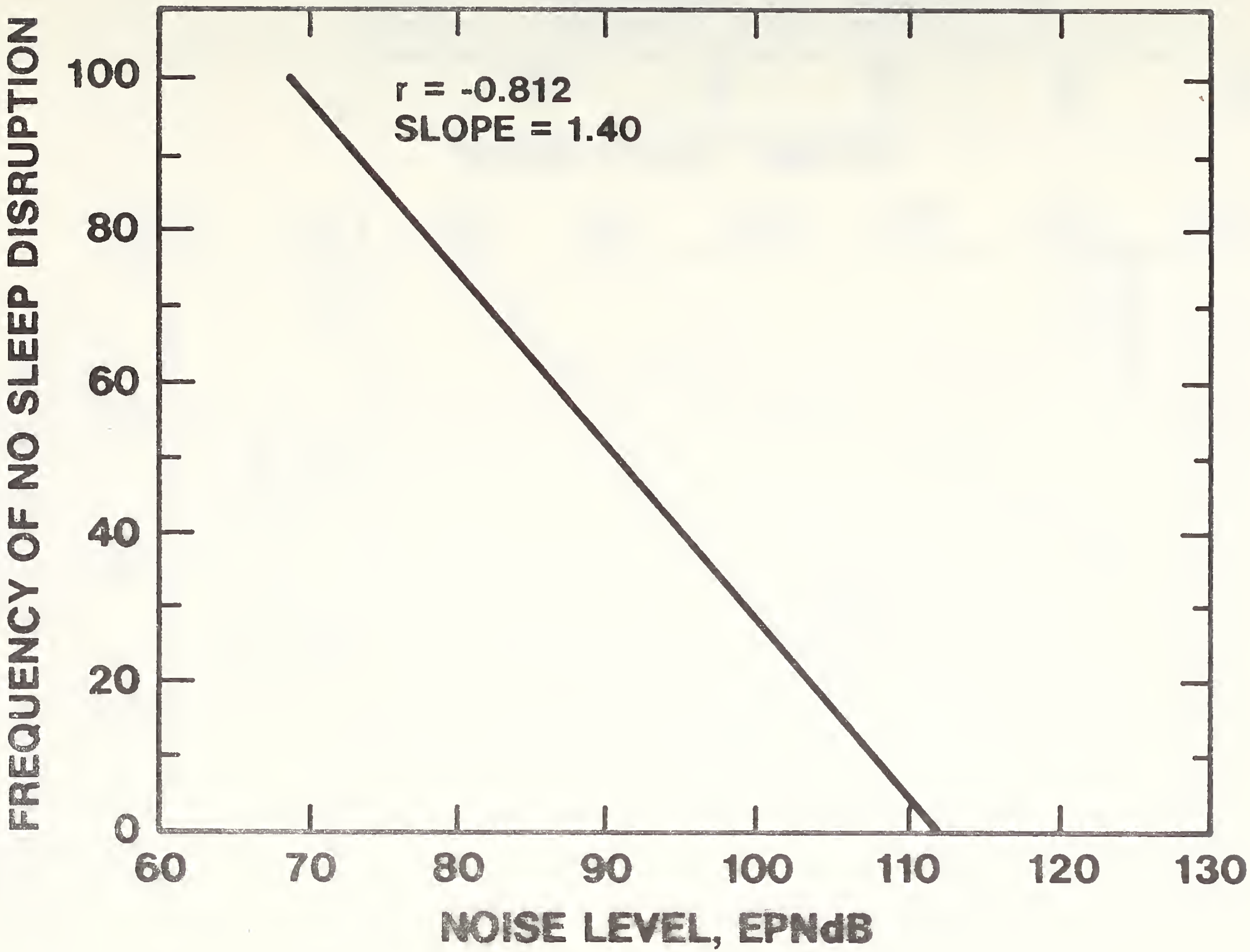

Figure 2. Frequency of "no sleep disruption" as a function of noise level. (Source: Lukas, 1975)

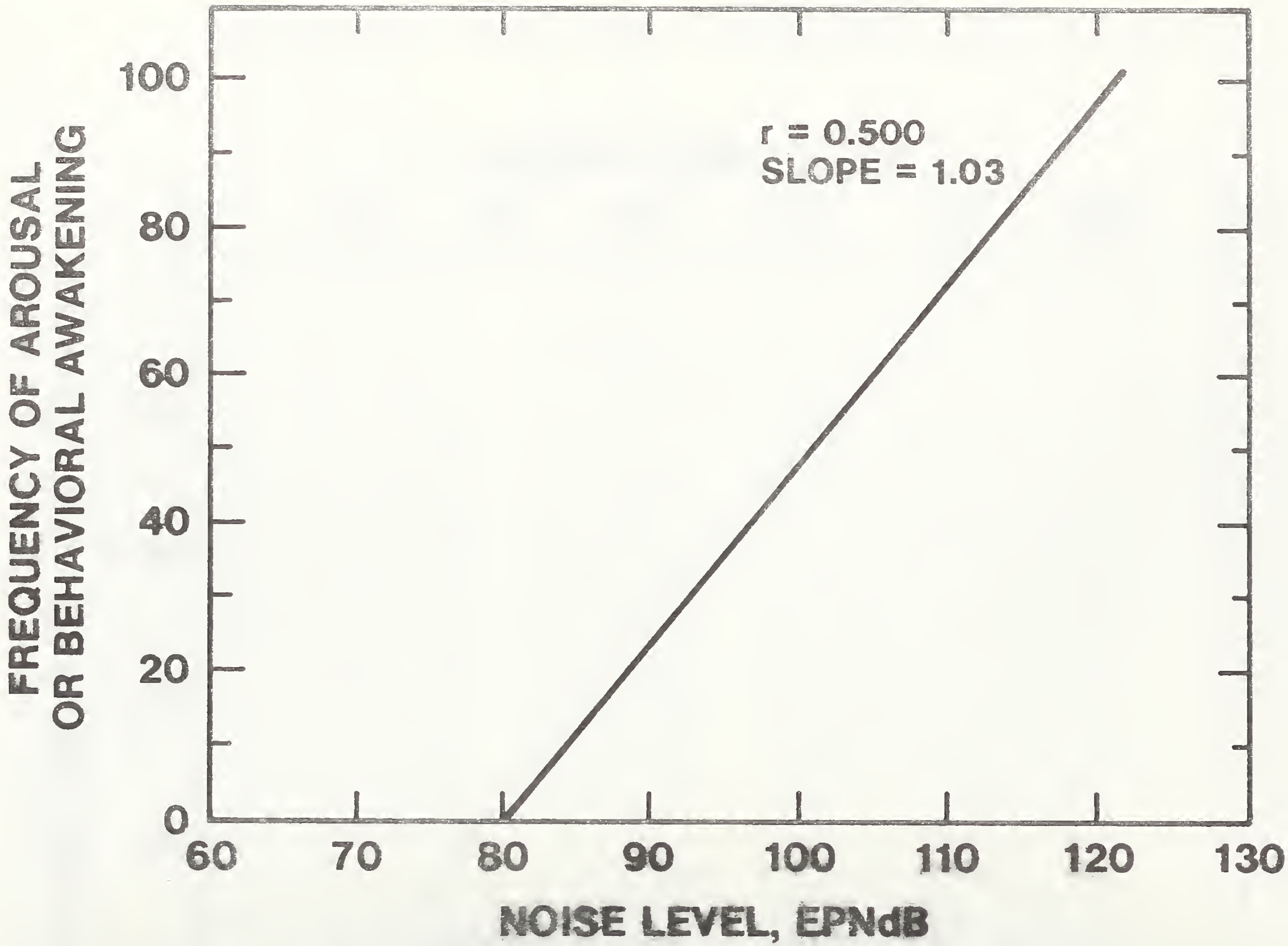

Figure 3. Frequency of arousal or behavioral awakening from sleep as a function of noise level. (Source: Lukas, 1975)

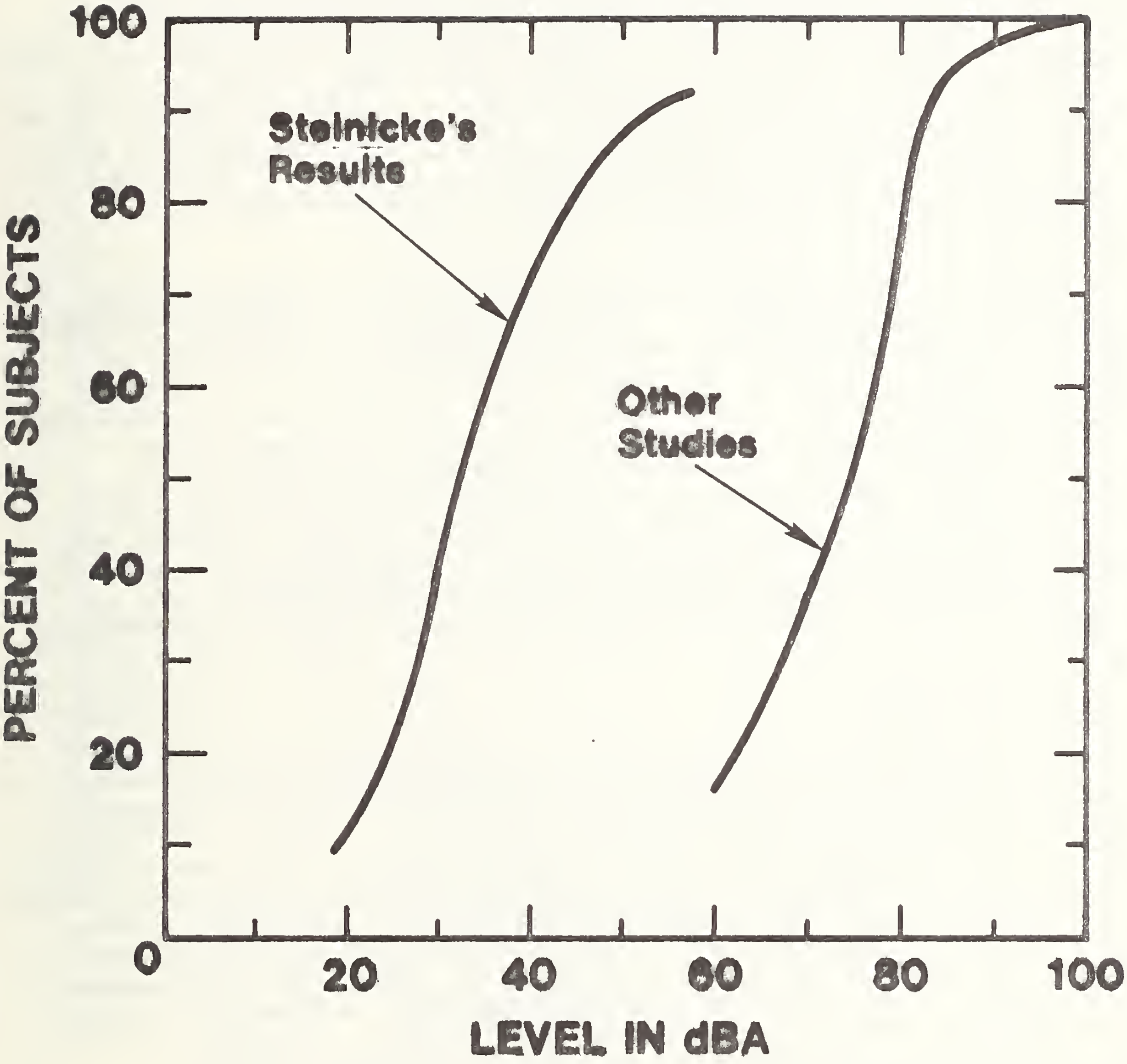

Figure 4. Frequency of arousal or behavioral awakening as a function of noise level. (Source: Lukas, unpublished)

Arousal by Non-Auditory Stimuli

Although all of the arousal threshold studies reviewed for this report have employed auditory stimuli, it should be recognized that other stimulus modalities might also be employed in alarm systems. Kravontka (1975), for example, describes a visual fire signal system for deaf school children. This system, of course, is designed for alerting building occupants who are awake. Considerably different problems than those addressed by Kravontka are encountered by severely hearing-impaired individuals who are sleeping.

Several investigations have utilized other non-auditory stimuli to produce arousal. Pisano, Rosadini, Rossi and Zattoni (1966) evaluated depth of sleep by studying the intensity of painful electric stimuli to the forearm necessary to produce arousal. Schmidt and Birns (1971) used a cold thermal stimulus in an investigation of the behavioral arousal threshold of sleeping infants. Differences in olfactory thresholds for infants in two sleep states were investigated by Murray and Campbell (1970). Although these and other stimuli clearly are capable of producing arousal, there does not appear to exist a body of literature which might suggest recommendations for appropriate signal characteristics for alarms using non-auditory stimuli.

Arousal and Drugs

Although there is substantial literature on the effects of drugs on sleep, very little data are available regarding the effects of drugs on human arousal thresholds. Given the high probability of regular drug use (tranquilizers, sleeping pills, pain relieving medication, etc.) among residents in nursing homes or other facilities for the aged, the effects of drugs on the ease with which people can be aroused in emergency situations becomes extremely important. It is clear that certain drugs do alter normal sleep patterns. Williams, Agnew and Webb (1966), for example, report that a single 200 mg dose of sodium pentobarbital administered just prior to sleep produced a significant reduction in REM and a slight increase in stage 4 when compared with the effects of a placebo. A single 800 mg dose of the tranquilizer meprobamate resulted in no change in the basic sleep pattern. However, 1200 mg of meprobamate at bedtime produced a decrease in REM. Secobarbital, a hypnotic prescribed to facilitate sleep, has been shown to alter sleep patterns by decreasing the time spent awake and in REM and increasing the amount of stage 2 (Potvin, et al., 1975).

Only two threshold studies were identified which demonstrate the effects of drugs on arousal thresholds. Bonnet (doctoral dissertation reported by Webb, personal communication, 1977) found a substantial increase in stage 2 arousal threshold after a single administration before sleep of 30 mg flurazepam or 100 mg pentobarbital. The effect was especially pronounced early in the night, but persisted at least six to seven hours into the sleep period. Caffeine, on the other hand, reduced waking thresholds and increased sleep onset latencies. Bonnet (1975) reports a pilot study involving threshold measurements after administration of Quaalude (methaqualene). Fifteen minutes before retiring, two subjects were given a standard 300 mg Quaalude tablet. Thresholds were determined using an ascending series and a button push response. Stage 2 AATs increased about 8 dB throughout the night as compared to a non-drug baseline night.

The relationship between drug use and effects on sleep is best understood for alcohol. Williams and Salamy (1972), in an extensive review of the effects of alcohol on sleep, note significant differences between the sleep of the chronic alcoholic and the moderate user. Sober, chronic alcoholics who are not delerious or hallucinating demonstrate normal amounts of REM sleep, but, with few exceptions, exhibit almost no short-wave (stage 3-4) sleep. Large increases in REM can occur during withdrawal from chronic intake of alcohol, amphetamines, barbiturates and morphine. Moderate or single doses of alcohol tend to cause early onset of sleep, small increases in cardio-respiratory rates accompanied by decreased motility and transient increases in delta sleep with a delay or inhibition of REM.

The little available data relevant to the effects of drugs on arousal from sleep clearly leave many questions unanswered. While it appears evident that at least some commonly used drugs do have a deleterious effect on arousal, very little can be said about the relationship between chronic use of drugs and the response of sleeping individuals to emergency alarms.

Conclusions and Implications for the Design of Emergency Alarms

The review of the literature in the preceding sections leads to the conclusion that currently available data do not provide an adequate basis for specifying the signal characteristics which will offer a high assurance of awakening a sleeping population. This conclusion is largely attributable to the fact that most of the research reviewed was not oriented

specifically toward providing such information. However, a number of generalizations regarding signaled arousals can be made. These generalizations have value primarily as hypotheses to be tested, rather than as principles to be incorporated into alarm specifications.

It is clear that the intensity of a signal sufficient to produce arousal is highly variable; individual differences in threshold are large. Generally, greater intensities are required to arouse subjects from delta sleep (stages 3 and 4) than from stage 2, which in turn requires a greater intensity than stage 1. The placement of REM sleep in this hierarchy is less clear, but when only intensity is considered, a signal which will produce arousal from stage 4 is also likely to produce arousal from REM.

Arousal is obtainable with a progressively less intense signal as the night progresses. However, this effect may be confounded with sleep stage, sleep duration and circadian (daily) rhythms.

In certain respects, older individuals may be considered easier to awaken than younger subjects due to the relatively low proportion (in some individuals absence) of delta sleep and the greater frequency of spontaneous arousals with increasing age. Increasing age may also be associated with decreased arousal thresholds within each stage of sleep. The presumed "advantages" in terms of increased ease of arousal associated with advanced age may be offset by the commonly found impairment in sensory/perceptual functioning which also accompanies increased age.

Individuals with symptoms of depression will tend to exhibit exaggerated degrees of the normal sleep changes associated with age.

Stimuli which have personal significance or meaning may produce arousal at lower levels of intensity than neutral stimuli. Further, previously neutral stimuli can obtain significance through learning or instruction. Clearly the motivation of individuals to respond predisposes awakening responses.

It is conceivable that signals may be incorporated in dreams and this may inhibit or delay awakening in response to a signal which would otherwise produce arousal.

Finally, the action of drugs on arousal, while not firmly established, may reduce the probability of awakening to a given signal.

These general conclusions, while arrived at independently, are compatable with those reached by the authors of other papers dealing with the subject of arousal from sleep by alarms (Bloom, 1971; Bixler, N.d.).

In addition to outlining the general conclusions drawn from the sleep literature, it is appropriate to mention that general principles for good alarm design have been provided by several authors (e.g., Deatherage, 1972; McCormick, 1964; Seminara, 1965). With few exceptions, however, these principles offer little assistance in specifying criteria for alarms which will reliably awaken people in fire situations. Signal design and selection criteria for use in other specific applications are also available. For example, Siegel and Crain (1960) provide guidelines for presenting cautionary-warning information in aircraft, Trucks and Adams (1975) specify procedures for auditory signals in industrial environments, and Keating and Loftus (1977) provide guidelines for vocal alarms directed at staff in hospitals and nursing facilities. Within the fire community there has been considerable controversy concerning the development of a standard fire alarm signal. While proponents of various signal types, for example the "slow whoop" (Humphreys, 1973; Gosswiller, 1975) and coded temporal patterns (Mande, 1975) offer many valid advantages of one type or another, no substantive information about arousal producing capabilities are identified.

Performance After Sudden Arousal

Given the situation in which an emergency alarm does awaken an individual, it is then necessary that he or she be capable of performing the appropriate life-safety activities. Although literature which bears on this issue was not exhaustively reviewed, several indications of post-arousal performance decrement should be noted.

Tebbs (1972), in a review of post-awakening performance as it relates to certain military operations suggests that "prior research has demonstrated the performance decrements may range from 25 percent to 360 percent. Yet, while it is well established that performance decrements may be expected in the post-arousal period, the determinants of the post-arousal decrement have not been well established." Among the factors which may affect post-arousal performance are: the sleep stage preceding awakening, the time of night during which awakening occurs, the nature of the required performance and the chronic anxiety level of the individual awakened.

Johnson (1973) suggests that effective responding can be expected to occur more quickly upon arousal from stage 2 or REM sleep than upon arousal from slow-wave (stage 3-4) sleep. Feinberg, Koresko and Heller (1967), however, note that on some occasions elderly, chronic brain syndrome patients, awakened from REM, displayed states of delerium with fixed ideas on which they attempted to act. Scott (1969) found that performance on a battery of reaction time, detection threshold and cognitive tasks showed marked decrement after abrupt arousal from all sleep stages with some trend (non-significant) for performance following REM awakenings to be superior to performance following NREM arousals. However, as Scott points out, none of the tasks on which his subjects were tested had the "arousing" quality which "fire" may have.

A number of studies show decrements in grip strength upon arousal (e.g., More, Jenkins and Barker, 1922; Jenneret and Webb, 1963; and Tebbs and Foulkes, 1966). While the effects of prior sleep length and sleep stage on this measure are somewhat ambiguous, Tebbs and Foulkes suggest that for tasks which require more intellectural involvement, it might be expected that performance would be more impaired after arousal from REM due to possible dream incorporation.

The transition from sleep to wakefulness is consistently shown to require considerable time. Seminara and Shavelson (1969) found that while the most rapid performance recovery by a space crew upon sudden arousal took place in the first three-minute period following arousal, the effects of drowsiness persisted up to 9 to 12 minutes following the alarm. Langdon and Hartman (1961) also provide data which indicate significant performance decrements on a psychomotor task for 10 minutes following arousal. Proficiency after 10 minutes approached but did not reach pre-sleep levels.

It is likely that the performance decrements observed upon abrupt arousal from sleep may be more severe if the individual is under the influence of tranquilizing or hypnotic drugs. Potvin, et al. (1975), found that the performance following arousal from stage 4 of subjects who had received secobarbital 1 to 1-1/2 hours earlier was slightly enhanced for tasks involving predictable speed and coordination. However, the drug impaired performance on unpredictable tasks requiring coordination and fast reactions. The authors note that the results of this study cannot be extended to prolonged use of secobarbital or to individuals performing highly skilled tasks under emergency conditions.

The implications of these data for performing life preserving activities in a fire situation after abrupt arousal are not immediately obvious. It is clear, however, that post-arousal behavior in such emergency conditions must be considered along with the evaluation of arousal per se. It is also conceivable that there is an interaction between post-arousal performance and the type of signal-producing arousal.

Recommendations for Future Studies of Arousal by Emergency Alarms

The literature reviewed regarding sleep and arousal does not provide the data required to recommend specifications for emergency alarms which will reliably awaken a substantial portion of the population in the event of a fire. This is not to suggest that many current systems may not be adequate, but rather that their efficacy in arousing sleeping individuals is largely unknown. Although it is unlikely that any single experimental effort will be capable of providing definitive alarm specifications for every environment in which there is a need to provide arousal-producing signals, many of the questions surrounding alarm specification are amenable to empirical solution. Some of the more important considerations which should be taken into account in the design of such experiments are discussed below.

Stimulus Characteristics and Presentation. A variety of signal characteristics including intensity, frequency, meaningfulness, and temporal pattern are appropriate for investigation. It is recommended that the initial focus of research should be to determine the signal intensity required to arouse the specified sleeping population. Other signal characteristics should be selected from existing alarm signals including smoke detectors, fire bells, and horns, etc. Subjects should be exposed to the experimental signal infrequently--no more that one to three exposures per experimental night--to minimize the effects of expectancy and any additive effects of repeated stimulation.

Subjects. Because of large differences in sleep and arousal as a function of age, sex, and physical and mental condition, selection of subjects becomes crucial if any generalizations regarding the "arousability" of alarms are to be made. Generalizations about arousal of nursing home populations, for example, made from studies of college students will be tenuous at best. Selection of subjects should take into account

decrements in hearing associated with aging to assure that experimental samples are representative of target populations. The influence of drugs upon arousal, particularly sedatives, provides an especially difficult problem for the researcher. The most rigorous test of the effects of such drugs on arousal would require a series of studies with specific drugs administered in various controlled doses with the appropriate experimental controls (including double blind paradigms and the use of placebos, etc.). It may be more expedient to include individuals who use such drugs in subject selection.

Experimental Environment. The choice of experimental setting for a study of alarm intensities sufficient to produce arousal is complicated by two incompatible requirements. First, experimental arousals should be carried out under conditions as much like those encountered in the normal sleep environment as possible. That is, the best setting for such experiments would be in the subjects' residence. Second, the sleep literature clearly indicates that sleep stage as defined by EEG patterns is an important determinant of arousability. Therefore, signals should be presented during identified sleep stages, especially stage 4 since in this stage individuals are particularly resistant to external stimuli. The only practical environment for the necessary recordings to be made is an established sleep laboratory. It is suggested that a two-phase approach be considered in any proposed research. The first, experimentally rigorous phase, would be carried out under laboratory conditions and the second, or validation phase, would be accomplished in a more natural, residental setting.

Measures of Arousal. As evidenced in the review of sleep literature, arousal can be defined by a variety of criteria including brain activity, behavioral responses and vocalizations. For the purposes of alarm specification, it is recommended that the subjects' response include a time dependent post-arousal task that is in some way comparable to the appropriate response in an actual fire situation. The response need not be physical evacuation. It should, however, be sufficient to demonstrate that the subjects have reached a level of arousal at which they can perform relatively simple decision-making tasks or other responses at a level comparable to the adaptive task.

Clearly, many other features of good experimental design must be considered in developing a research program aimed at empirically determining the characteristics of emergency signals which will arouse individuals to a state in which appropriate life saving action can be taken. The obvious necessity of providing effective fire alarm systems, particularly in institutional environments, suggests that such a research program be instituted.

REFERENCES

1. Agnew, H.W., Shaw, D.I., and Webb, W.B. Difficulty in arousing human subjects from stage 4 sleep. Unpublished abstract.

2. Agnew, H.W., Jr., Webb, W.B., and Williams, R.L. Sleep patterns in late middle age males: An EEG study. Electroencephalography and Clinical Neurophysiology, 1967, 23, 168-171.

3. Agnew, H.W., Jr. and Webb, W.B. Sleep latencies in human subjects: Age, prior wakefulness, and reliability. Psychonomic Science, 1971, 24(6), 253-254.

4. Aserinsky, E. and Kleitman, N. Regularly occuring periods of eye motility and concomitant phenomena during sleep. Science, 1953, 181, 273-274.

5. Bixler, E.O. Emergencies: Arousal from sleep. N.d.

6. Bloom, R.F. Arousal From Sleep by Audible Alarms: Guidelines From Experimental and Clinical Research. (Report for Mosler Electronic Systems). Danbury, Co., January 1971.

7. Bonnet, M. An examination of the depth of sleep research. Unpublished review. University of Florida, 1975.

8. Bradley, C. and Meddis, R. Arousal threshold in dreaming sleep. Physiological Psychology, 1974, 2(2), 109-110.

9. Brezinova, V. The number and duration of the episodes of the various EEG stages of sleep in young and older people. Electroencephalography and Clinical Neurophysiology, 1975, 39, 273-278.

10. Broch, J.T. The Application of the Bruel & Kjaer Measuring Systems to Accoustic Noise Measurements. Denmark: Bruel & Kjaer, 1969.

11. Davies, D.R. Individual differences in sleep patterns, Postgraduate Medical Journal, 1976, 52, 10-13.

12. Davis, et al. Changes in human brain potentials during the onset of sleep. Science, 1937, 86, 448-450.

13. Deatherage, B.H. Auditory and other sensory forms of information presentation. In Van Cott, H.P. and Kinkade, R.G. (Eds.) Human Engineering Guide to Equipment Design, Joint Army-Navy-Airforce Steering Committee, 1972.

14. Dement, W.C. and Kleitman, N. Cyclic variations in EEG during sleep and their relation to eye movements body motility and dreaming. Electroencephalography and Clinical Neurophysiology, 1957, 9, 673 -

15. Derry, L. A study of United States fire experience, 1976. Fire Journal, November 1977, 50-53.

16. Feinberg, I., Koresko, R.L. and Heller, N. EEG sleep patterns as a function of normal and pathological aging in man, Journal of Psychiatic Research, 1967, 5, 107-144.

17. Gosswiller, E. The slow whoop: An alternative standard fire alarm signal. Fire Journal, September 1975, 21.

18. Gresham, S.C., Agnew, H.W., Jr., and Williams, R.L. The sleep of depressed patients. Archives of General Psychiatry, 1965, 13, 503-507.

19. Howarth, C.I. and Ellis, K. The relative intelligibility threshold for one's own name compared with other names. Quarterly Journal of Experimental Psychology, 1961, 13, 236-239.

20. Humphreys, W.Y. The alarming problem. Fire Journal, September 1973, 15-17.

21. Jeanneret, P.R. and Webb, W.B. Strength of grip on arousal from full night's sleep. Perceptual and Motor Skills, 1963, 17, 759-761.

22. Johnson, L.C. Are stages of sleep related to waking behavior? American Scientist, 1973, 61, 326-338.

23. Kales, A., Wilson, T., Kales, J.D., Jacobsen, A., Paulson, M.J., Kollar, E., and Walter, R.S. Measurements of all-night sleep in normal elderly persons: Effects of aging. Journal of the American Society, 1967, 15(5), 405-414.

12. Davis, et al. Changes in human brain potentials during the onset of sleep. Science, 1937, 86, 448-450.

13. Deatherage, B.H. Auditory and other sensory forms of information presentation. In Van Cott, H.P. and Kinkade, R.G. (Eds.) Human Engineering Guide to Equipment Design, Joint Army-Navy-Airforce Steering Committee, 1972.

14. Derry, L. A study of United States fire experience, 1976. Fire Journal, November 1977, 50-53.

15. Dement, W.C. and Kleitman, N. Cyclic variations in EEG during sleep and their relation to eye movements body motility and dreaming. Electroencephalography and Clinical Neurophysiology, 1957, 9, 673 -

16. Feinberg, I., Koresko, R.L. and Heller, N. EEG sleep patterns as a function of normal and pathological aging in man, Journal of Psychiatic Research, 1967, 5, 107-144.

17. Gosswiller, E. The slow whoop: An alternative standard fire alarm signal. Fire Journal, September 1975, 21.

18. Gresham, S.C., Agnew, H.W., Jr., and Williams, R.L. The sleep of depressed patients. Archives of General Psychiatry, 1965, 13, 503-507.

19. Howarth, C.I. and Ellis, K. The relative intelligibility threshold for one's own name compared with other names. Quarterly Journal of Experimental Psychology, 1961, 13, 236-239.

20. Humphreys, W.Y. The alarming problem. Fire Journal, September 1973, 15-17.

21. Jeanneret, P.R. and Webb, W.B. Strength of grip on arousal from full night's sleep. Perceptual and Motor Skills, 1963, 17, 759-761.

22. Johnson, L.C. Are stages of sleep related to waking behavior? American Scientist, 1973, 61, 326-338.

23. Kales, A., Wilson, T., Kales, J.D., Jacobsen, A., Paulson, M.J., Kollar, E., and Walter, R.S. Measurements of all-night sleep in normal elderly persons: Effects of aging. Journal of the American Society, 1967, 15(5), 405-414.

24. Keating, J.P. and Loftus, E.F. Vocal emergency alarms in hospitals and nursing facilities: Practice and potential (NBS-GCR-77-102). Washington, D.C.: National Bureau of Standards, July 1977.

25. Keefe, F.B., Johnson, L.C., and Hunter, E.J. EEG and autonomic response pattern during waking and sleep stages. Psychophysiology, 1971, 8(2), 198-212.

26. Kravontka, S.J. A fire signal for deaf school children, Fire Technology, 1975, 11(1).

27. Kryter, K.D. The Effects of Noise on Man, New York: Academic Press, 1970.

28. Langdon, D.E. and Hartman, B. Performance Upon Sudden Awakening (U.S.A.F. School of Aerospace Medicine Report 62-16). November 1961.

29. Langford, G.W., Meddis, R., and Pearson, A.J.D. Awakening latency from sleep for meaningful and non-meaningful stimuli. Psychophysiology, 1974, 11(1), 1-5.

30. LeVere, T.E., Davis, N., Mills, J., and Berger, E.H. Arousal from sleep: The effects of the cognitive value of auditory stimuli. Physiological Psychology, 1976, 4(3), 376-382.

31. Loomis, A.I., Harvey, F.N., and Hobart, G. Cerebral states during sleep as studied by human brain potentials. Journal of Experimental Psychology, 1937, 21, 127.

32. Lukas, J.S. Measures of Noise Level: Their Relative Accuracy in Predicting Objective and Subjective Responses to Noise During Sleep (PB-257 683). Washington, D.C.: U.S. Environmental Protection Agency, September 1975.

33. Lukas, J.S. Noise and sleep: A literature review and a proposed criterion for assessing effects. Journal of the Accoustical Society of America, 1975a, 58(6), 1232-1242.

34. Lukas, J.S. A proposed criterion for assessing the effects of noise on sleep. Unpublished manuscript.

35. Mände, I. A standard fire alarm signal: Temporal or "slow whoop." Fire Journal, November 1975, 25-28.

36. McCormick, E.J. Human Factors Engineering, New York: McGraw-Hill, 1964.

37. Monroe, L.J. Psychological and physiological differences between good and poor sleepers. Journal of Abnormal Psychology, 1967, 72, 255.

38. More, L.M., Jenkins, L.M., and Barker, L. Relation of number of hours sleep to muscular efficiency. American Journal of Physiology, 1922, 59, 471.

39. Murray, B. and Campbell, D. Differences between olfactory thresholds in two sleep states in the newborn infant, Psychonomic Science, 1970, 18(6).

40. Oswald, I., Taylor, A.M., and Treisman, M. Discriminative responses to stimulation during human sleep. Brain, 1960, 83, 440-453.

41. Pisano, M., Rosadini, G., Rossi, G.F., and Zattoni, J. Relations between threshold of arousal and electroencephalographic patterns during sleep in man, Physiology and Behavior, 1966, 1, p. 55-58.

42. Potvin, A.R., Salamy, J.G., Crossier, W.G., Jones, K.W., and Doerr, J.A. Effects of secobarbital on performance upon arousal from stage 4 sleep. Applied Neurophysiology, 1975, 38, 240-250.

43. Rechtschaffen, A., Hauri, P., and Zeitlin, M. Auditory awakening thresholds in REM and NREM sleep stages. Perceptual and Motor Skills, 1966, 22, 927-942.

44. Rechtschaffen, A. and Kales, A. (Eds.) The Manual of Standardized Terminology, Techniques and Scoring Systems for Sleep Stages of Human Subjects (National Institutes of Health Publication No. 204). Washington, D.C., 1968.

45. Schmidt, K. and Birns, B. The behavioral arousal threshold in infact sleep as a function of time and sleep state, Child Development, 1971, 42, 269-277.

46. Scott, J. Performance after abrupt arousal from sleep: Comparison of a simple motor, a visual-perceptual, and a cognitive task. Proceedings, 77th Annual Convention of the American Psychological Association, 1969, 225-226.

47. Seminara, J.L. How to apply human factors principles in warning systems design, Machine Design, September 1965, 107-116.

48. Seminara, J.L. and Shavelson, R.J. Effectiveness of space crew performance subsequent to sudden sleep arousal. Aerospace Medicine, 1969, 40(7), 723-727.

49. Shapiro, A., Goodenough, D.R., and Gryler, R.B. Dream recall as a function of method of awakening. Psychosomatic Medicine, 1963, 25(2), 174-180.

50. Siegel, A.I. and Crain, K. Experimental investigations of cautionary signal presentations. Ergonomics, 1960, 3, 339-356.

51. Tebbs, R.B. Post-awakening Visualization Performance as a Function of Anxiety Level, REM or NREM Sleep, and Time of Night (SRL-TR-72-005). U.S. Air Force Systems Command, February 1972.

52. Tebbs, R.B. and Foulkes, D. Strength of grip following different stages of sleep. Perceptual and Motor Skills, 1966, 23, 827-834.

53. Trucks, L.B. and Adams, S.K. Predicting the effectiveness of auditory warning signals in industrial environments. Proceedings Human Human Society 19th Annual Meeting, October 1975, 368-374.

54. Tune, G.S. Sleep and wakefulness in 509 normal human adults. British Journal of Medical Psychology, 1969, 42, 75-80.

55. Tune, G.S. The influence of age and temperament on the adult human sleep-wakefulness pattern. British Journal of Psychology, 1969, 60, 431.

56. Watson, R. and Rechtschaffen, A. Auditory awakening thresholds and dream recall in NREM sleep. Perceptual and Motor Skills, 1969, 29, 635-644.

57. Webb, W.B. The nature of all night sleep patterns. Activita Nervosa Superior , 1969, 90-97.

58. Webb, W.B. Sleep as a biorhythm in W.P. Colquhoun (Ed.) Biological Rhythms and Human Performance. London: Academic Press, 1971.

59. Webb, W.B. Personal communication, 1977.

60. Webb, W.B. and Agnew, H. Measurement and characteristics of nocturnal sleep [In Abt, L.F. and Riess, B.F. (Eds.)]. _Progress is Clinical Psychology_, _8_, New York: Green and Stratton, 1969.

61. Webb, W.B. and Swinburne, H. An observational study of sleep of the aged. _Perceptual and Motor Skills_, 1971, _32_, 895-898.

62. Williams, H.L., Hammock, J.T., Daly, R.L., Dement, W.C., and Lubin, A. Response to auditory stimulation, sleep loss and the EEG stages of sleep. _Electroencephalography and Clinical Neurophysiology_, 1964, _16_, 269-279.

63. Williams, H.L., Morloch, H.C., Jr., and Morloch, J.V. _Discriminative Responses to Auditory Signals During Sleep_. Paper presented at the American Psychological Association Convention, Philadelphia, Pennsylvania, August 1963.

64. Williams, H.L. and Salamy, A. Alcohol and sleep [In Kissin, B. and Begleiter, H. (Eds.)] _The Biology of Alcoholism_, Volume 2 Physiology and Behavior, New York: Plenum, 1972.

65. Williams, R.L., Agnew, H.W., and Webb, W.B. Effects of drugs and disease on the EEG patterns in human sleep. _Proceedings of the IV World Congress of Psychiatry, September 5-11, 1966, Madrid, 3093-3096._

66. Williams, R.L., Karacan, J., and Hursch, C.J. _EEG of Human Sleep: Clinical Applications_, New York: Wiley, 1974.

67. Wilson, W.P. and Zung, W.W.K. Attention, discrimintation and arousal during sleep. _Archives of General Psychiatry_, 1966, _15_, 523-528.

68. Zimmerman, W.B. Sleep mentation and auditory awakening thresholds. _Psychophysiology_, 1970, _6_(5), 540-549.

69. Zung, W.W.K. and Wilson, W.P. Response to auditory stimulation during sleep. _Archives of General Psychiatry_, 1961, _4_, 548-552.

70. Zung, W.W.K., Wilson, W.P. and Dodson, W. Effect of depressive disorders on sleep EEG responses. _Archives of General Psychiatry_, 1964, _10_, 439-445.

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 78-1484 (HEW)	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE	5. Publication Date
Arousal from Sleep by Emergency Alarms: Implications from the Scientific Literature	June 1978
	6. Performing Organization Code
7. AUTHOR(S) V.J. Pezoldt and H. P. Van Cott	8. Performing Organ. Report No.
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234	10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)* Department of Health, Education and Welfare Public Health Service	13. Type of Report & Period Covered Final 14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A review of the sleep research and other scientific literature pertaining to the arousal of sleeping individuals by external stimuli is reported. This effort was undertaken to provide information about the characteristics of emergency alarms which will reliably awaken a sleeping population, especially nursing home residents, in the event of fire. The literature reviewed does not provide an adequate basis for specifying signal characteristics which will offer a high assurance of producing arousal. Among the factors that influence the intensity of a signal which will produce arousal are the age and physical/mental condition of the sleeper, drug use, sleep stage, time of night, and meaningfulness or personal significance of the signal. Data relevant to these variables are discussed as is the problem of performance following abrupt arousal. Recommendations regarding stimulus characteristics, measures of arousal and the experimental environment for future studies of arousal by emergency alarms are presented.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Alarms; arousal; auditory arousal thresholds; emergency signals; fire alarms; sleep research

18. AVAILABILITY [XX] Unlimited	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
[ ] For Official Distribution. Do Not Release to NTIS	UNCLASSIFIED	37
[ ] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13	20. SECURITY CLASS (THIS PAGE)	22. Price
[XX] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	UNCLASSIFIED	$4.50

USCOMM-DC 29042-P74